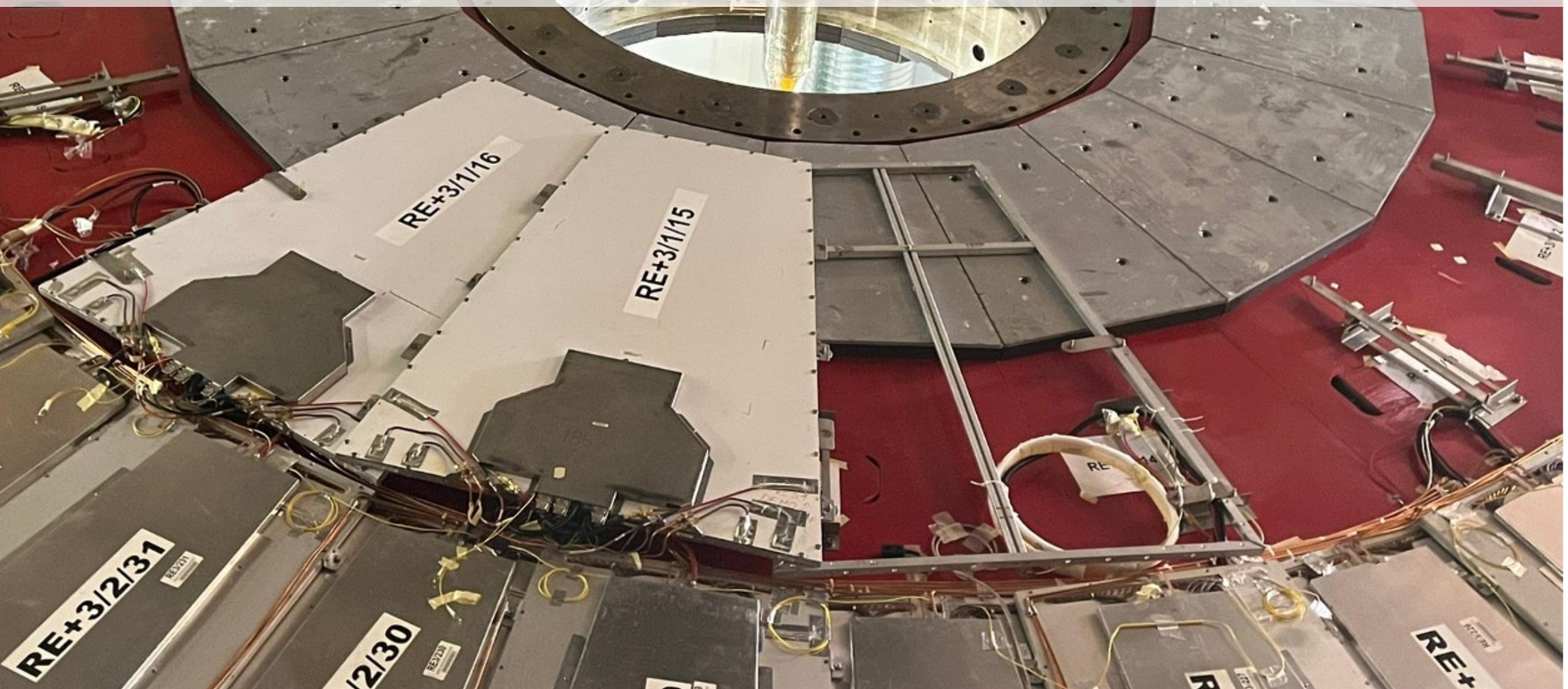
The new improved RPCs of CMS prevailing the challenges of High-Lumi LHC



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On behalf of the CMS MUON Group

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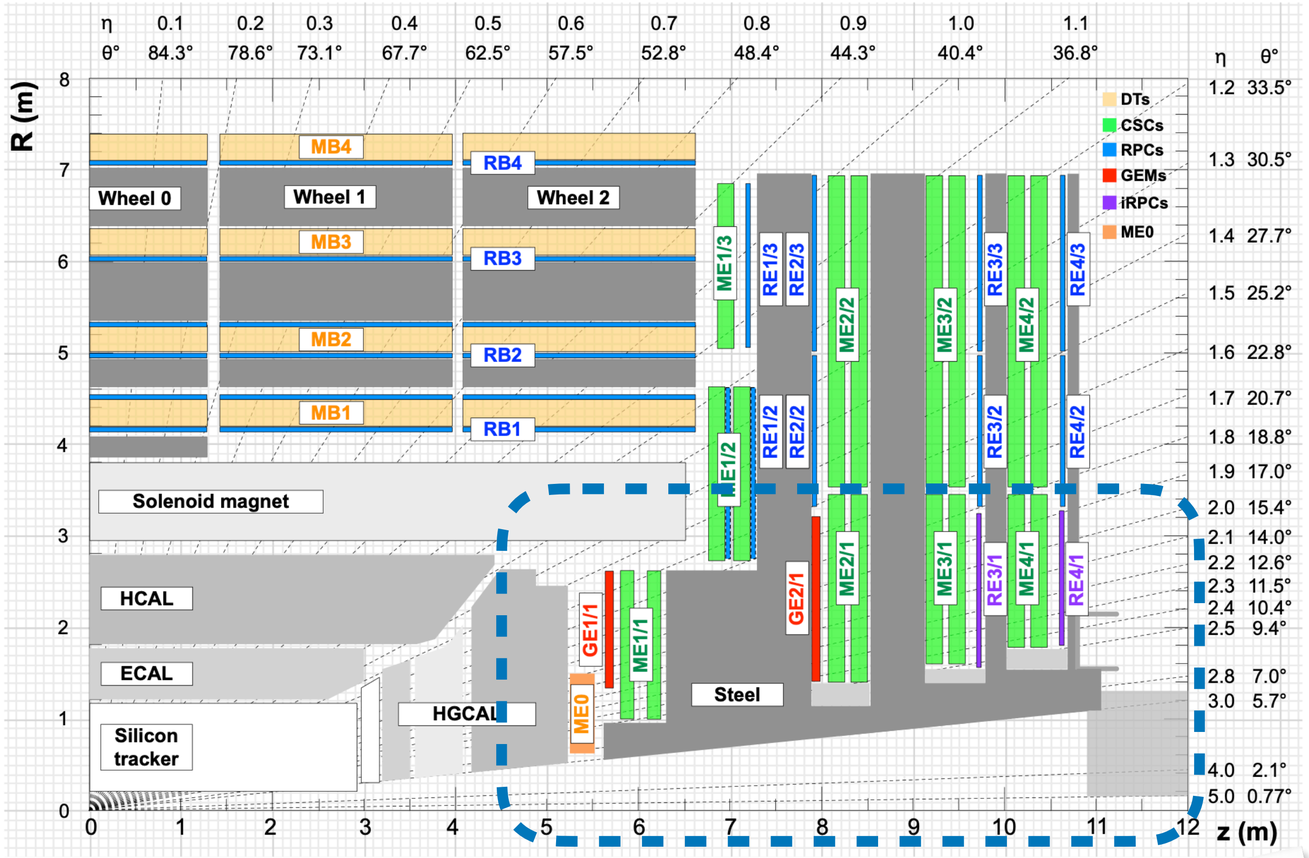
CMS Muon HL-LHC upgrade

In order to cope with the high particle rate and high pileup environment of the HL-LHC, the CMS MUON system has been upgraded during the LS2.

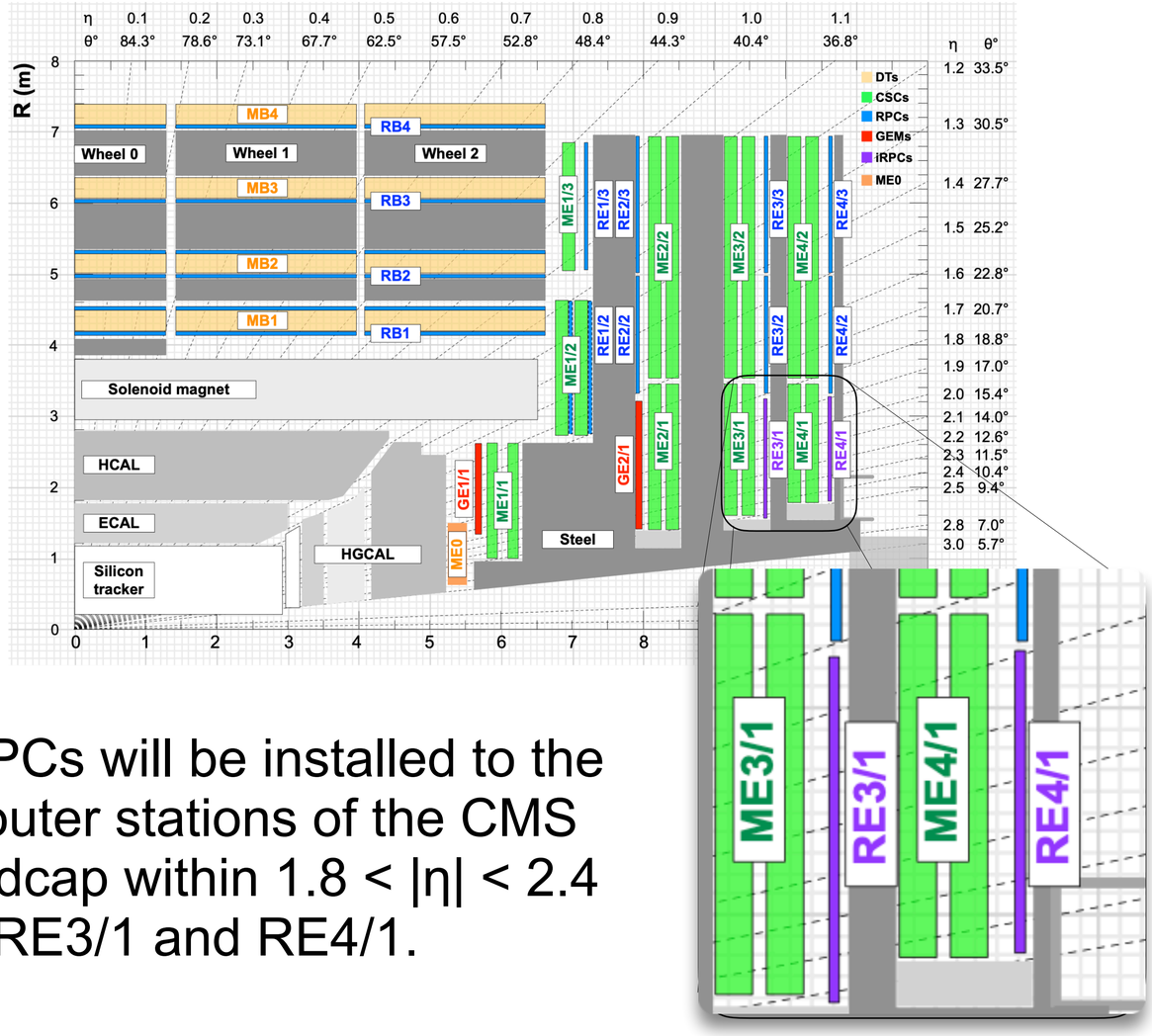
- Upgrade detector electronics
- Replacement of ageing electronic parts
- Increase event reconstruction capabilities particularly in forward region
- Extend acceptance



Focus of the talk is improved RPCs (iRPCs)

More details

CMS RPC HL-LHC upgrade

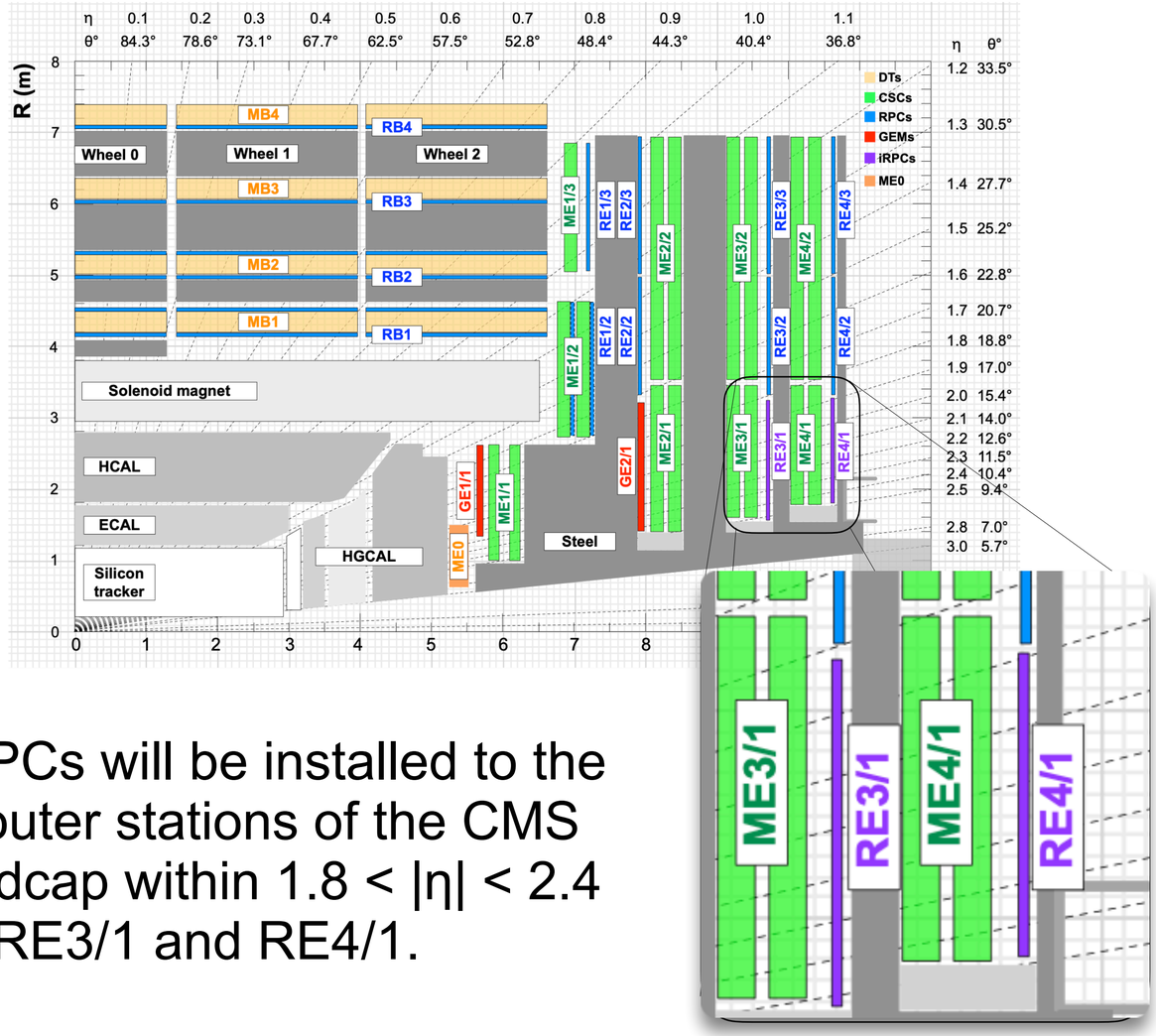


iRPCs will be installed to the 2 outer stations of the CMS endcap within 1.8 < |η| < 2.4 in RE3/1 and RE4/1.

	Present system	iRPC
|η| coverage	0 – 1.9	1.8 – 2.4
Max expected rate (Safety factor SF = 3 included)	600 Hz/cm^2	2 kHz/cm^2
Max integrated charge at 3 ab^{-1} (SF = 3 included)	~ 0.8 C/cm^2	~ 1.0 C / cm^2
ϕ granularity	~ 0.3 °	~ 0.2°
η resolution	~ 20 cm	~ 2 cm
T resolution	1.5 ns	< 1 ns

- New detector front-end electronics are validated
- Reduced electrode and gas gap thickness (1.4 mm vs present 2 mm)

CMS RPC HL-LHC upgrade



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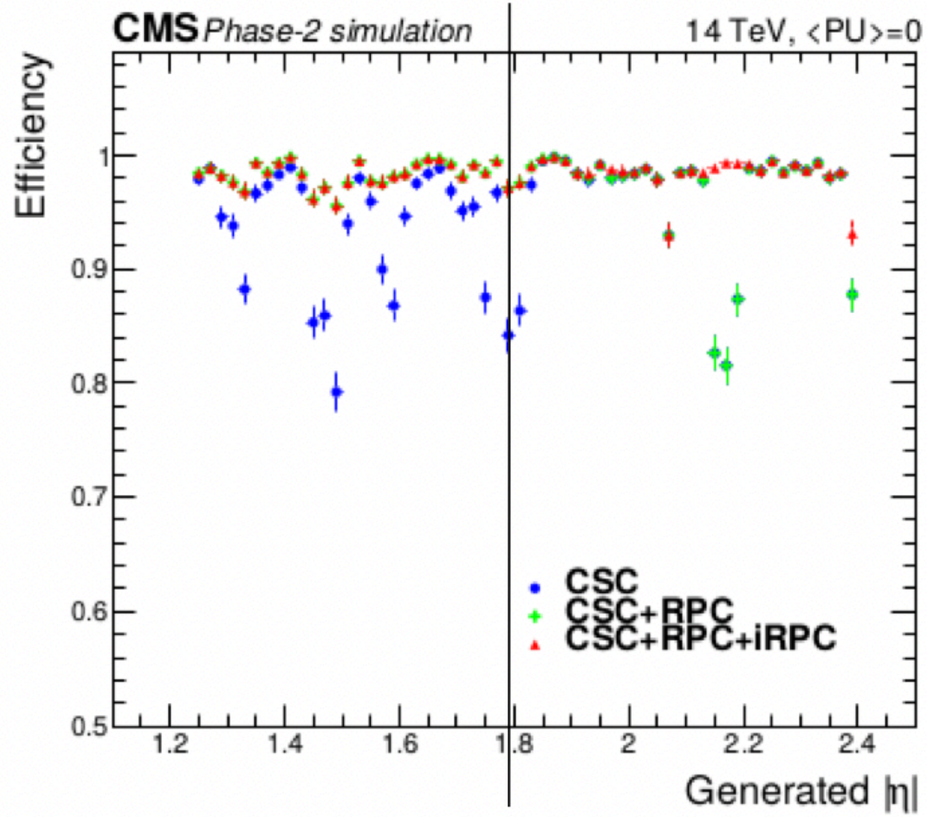
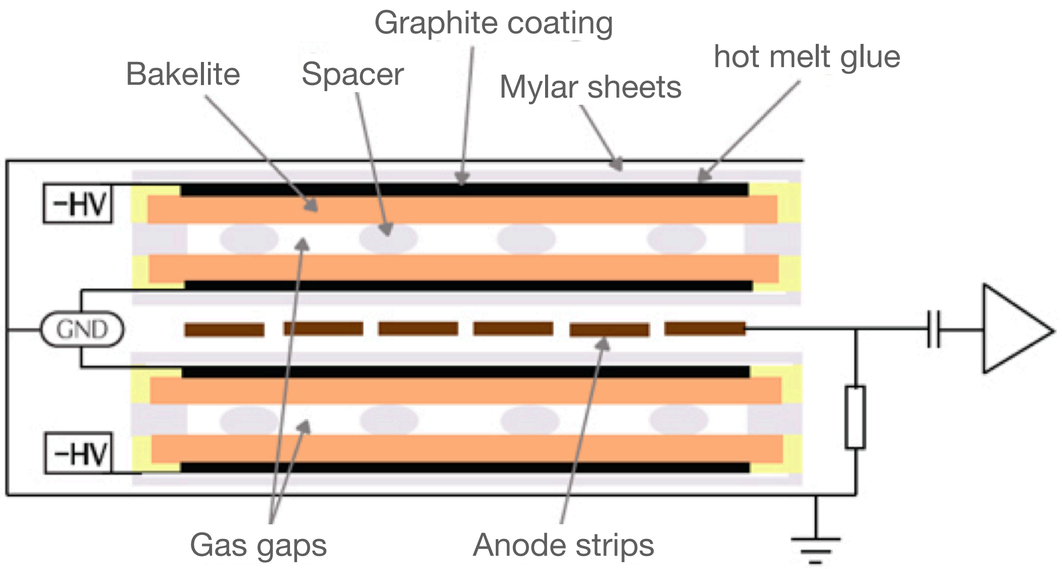


Efficiency > 90% everywhere if iRPC hits in the endcap muon track finder trigger algorithm RE4/1.

The iRPC chamber



- Double-gap iRPC detectors
- Each gap made of two 1.4 mm low-resistivity (order of $10^{10}\,\Omega$cm)
- High Pressure Laminate electrodes Separated by a gas gap of the same thickness.

- The new layout reduces the amount of the avalanche charge produced by the passage of a charged particle through the detector.
- This improves the RPC rate capability by reducing the needed time to collect this charge.

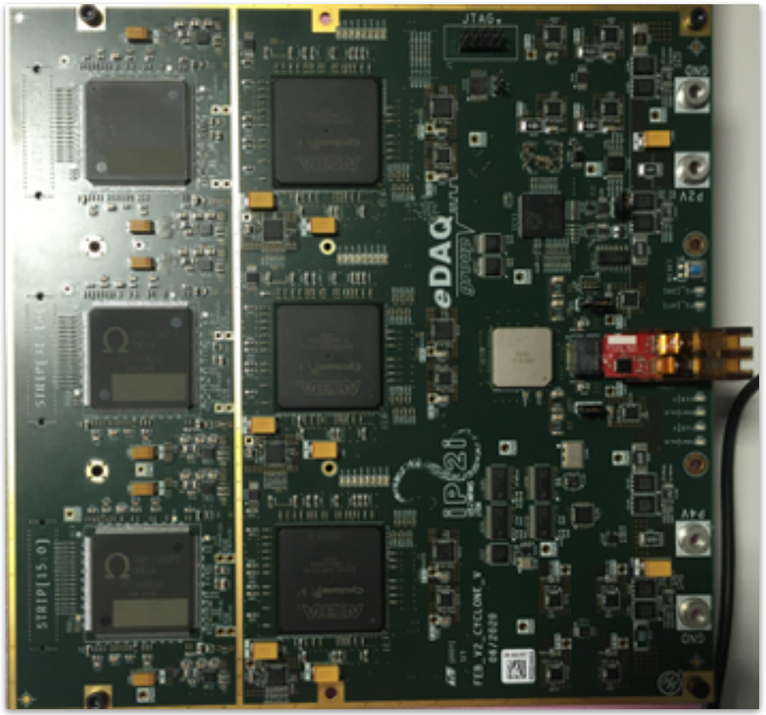
The iRPC front-end electronic

To cope with the lower charge signal of the iRPC at the same time to keep the iRPC efficiency high, the new front-end electronics are designed.

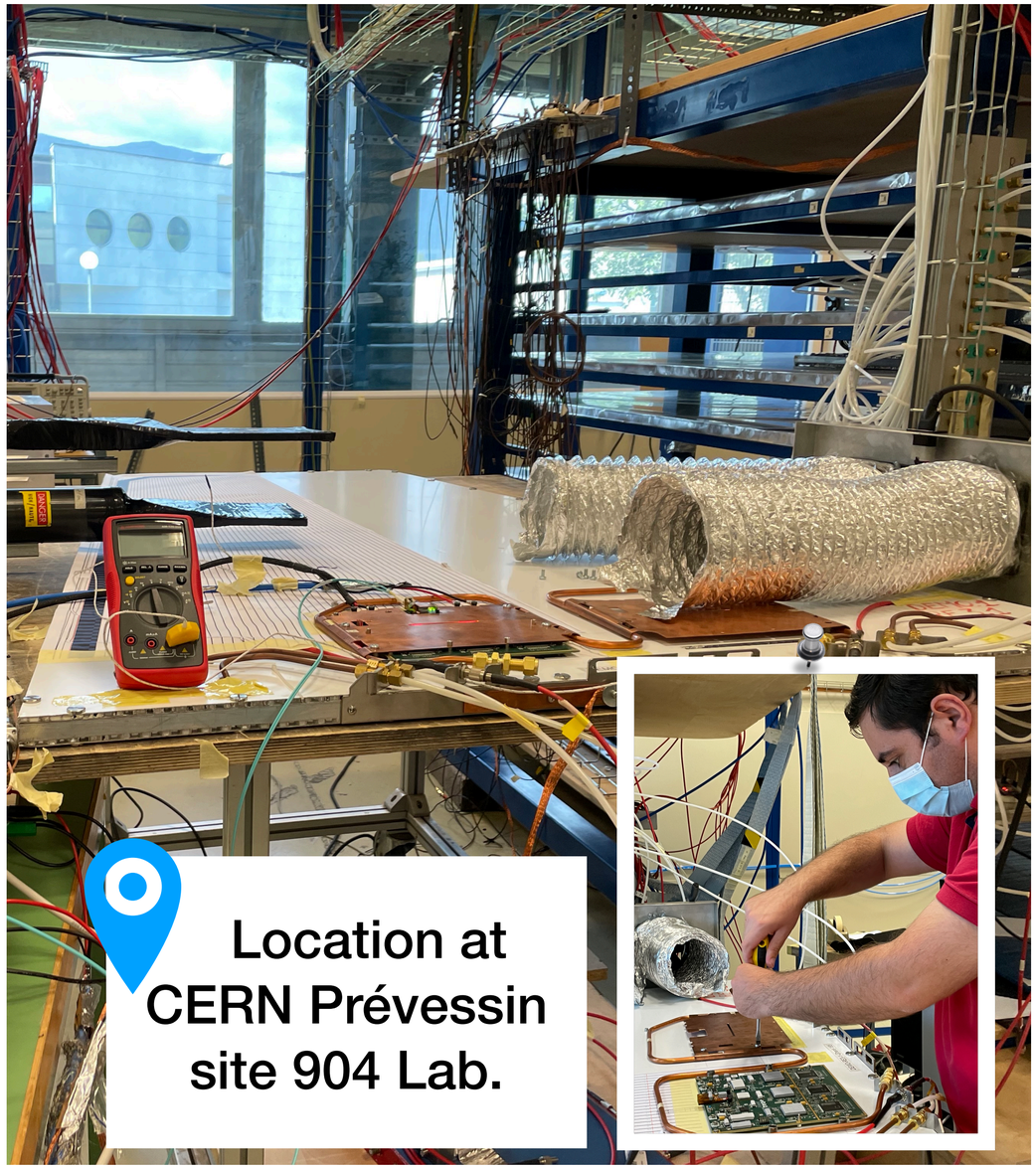
The new FEB is sensitive, has low-noise and high time resolution.

The FEB composed of :

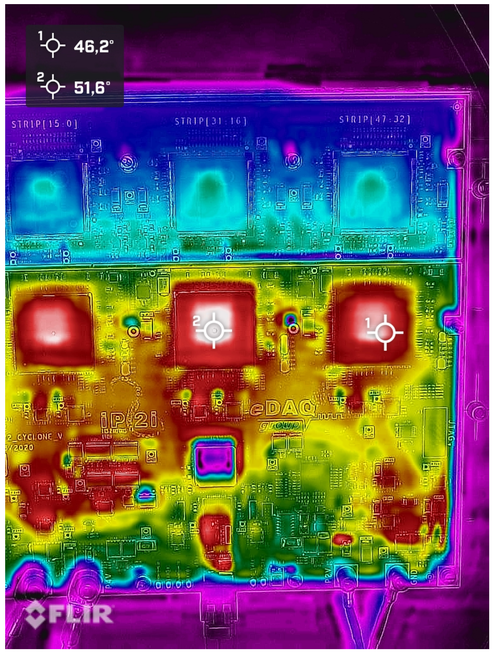
- 3 Erni connectors with 32 channels each
- 6 ASICs PETIROC 2C (top & bottom)
- 3 FPGAs Cyclone V (non rad-hard)
- GBTx/ GBT-SCA/VTRx.



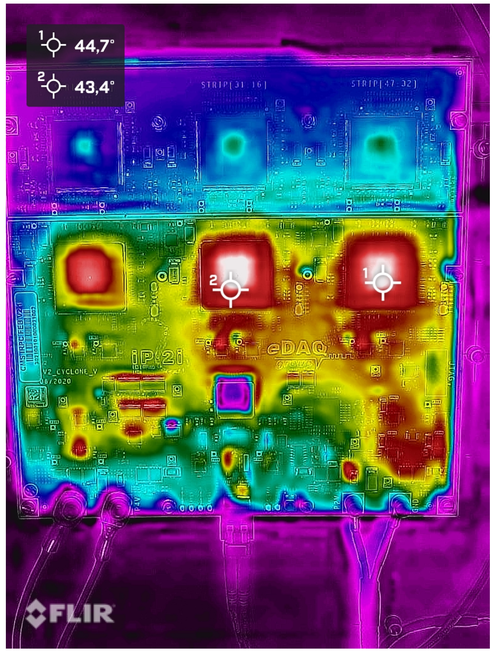
Success in cooling



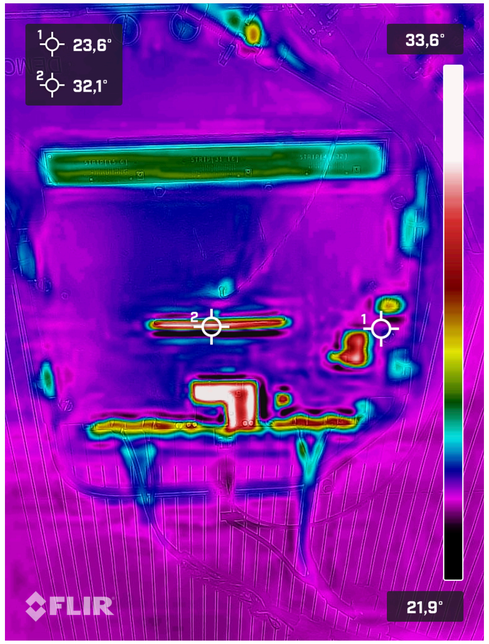
Location at CERN Prévessin site 904 Lab.



No cooling



Fan cooling

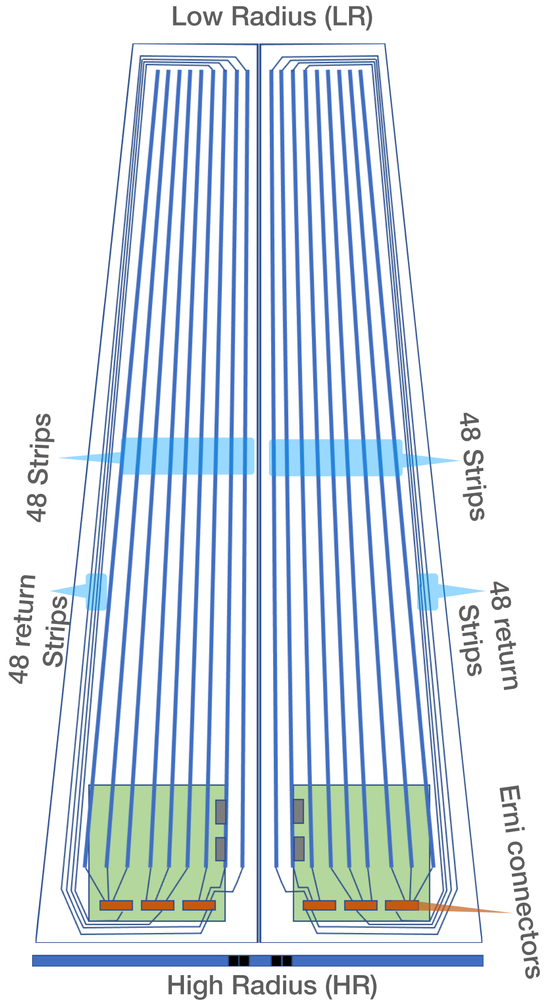


With cooling plate, Measurement with sensor:
fpga 2: ~30C

good cooling + cooling plate =
much less noise
uniform and low (<0.03Hz/cm^2)
noise among strips

Readout principle of the iRPC

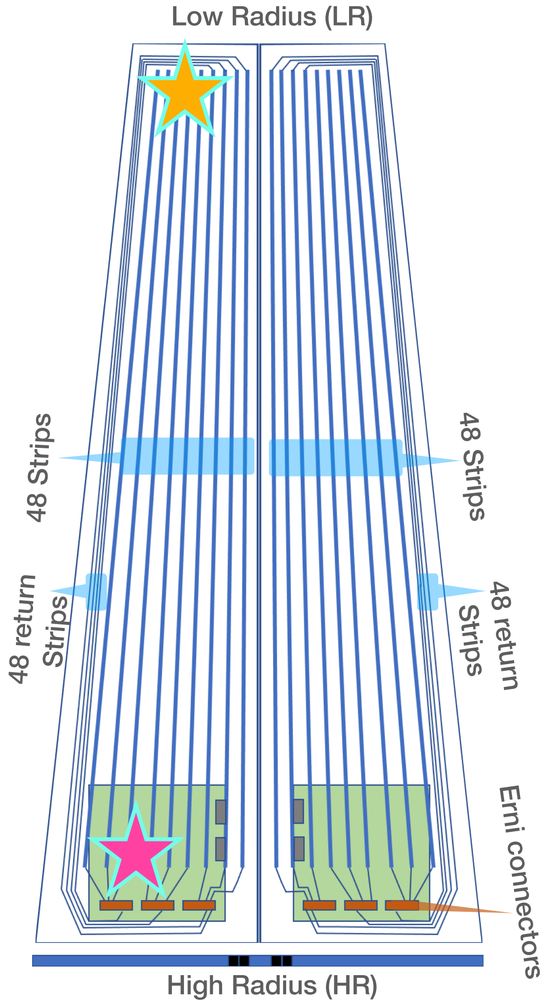
The LHC Beam Pipe:



- Two readout panels: made of a thin (0.6 mm) Printed Circuit Board (PCB)
- Each PCB has 48 strips and equipped with a FEB.
- To identify the position along the strip, the read out of the iRPC detectors is from both sides of a strip end, low radius (LR) and high radius (HR).

Readout principle of the iRPC

The LHC Beam Pipe:

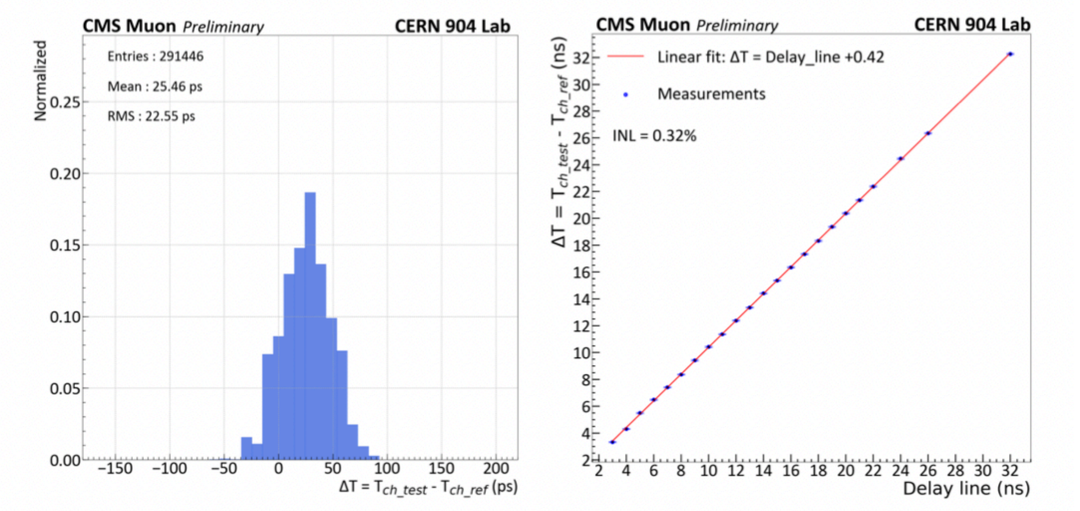


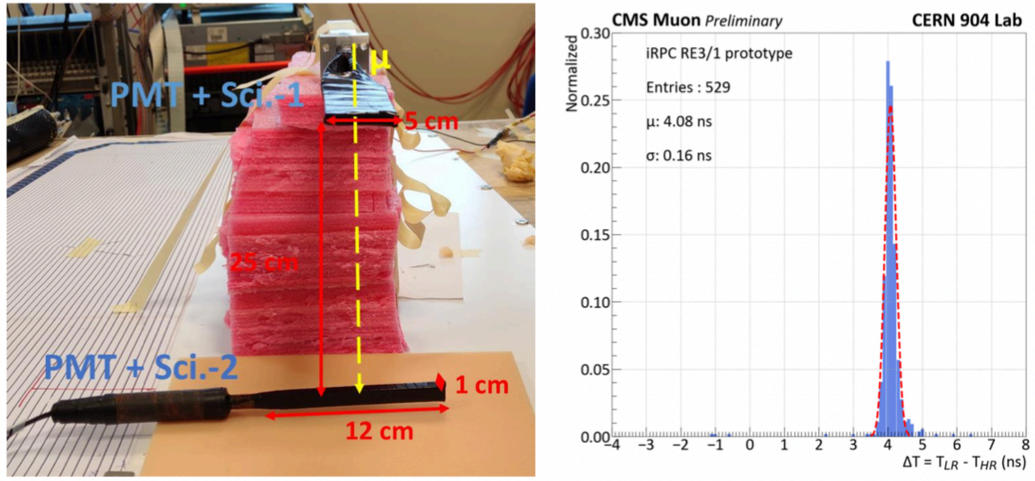
- 3 Erni connectors for each of the FEB
- Total 96 channels
- The 2 ends of a strip is connected to a different PETIROC
- The position of the particle hit along the strip: time difference between the two signal arrival times.

Max delta time =
Strip + (LR to erni) - (HR to Erni) ~= 20 ns

Min delta time =
(LR to erni) - strip - (HR to Erni)
~= 4 ns

Time and Space resolution





- The time difference between two channels without delay line is measured : RMS of 23 ps
- As the value of the delay line increases, the time difference between the two channels also increases linearly, with a maximum deviation of 0.1 ns.
- A strip is randomly chosen within the coincidence area of the two scintillators.
- The time difference distribution between both ends σ is 160 ps after rejecting the noise, which translates to a positional resolution of 1.5 cm along the strip using the formula $\Delta y = (v \times \Delta T)/2$

Gamma irradiation facility:GIF++

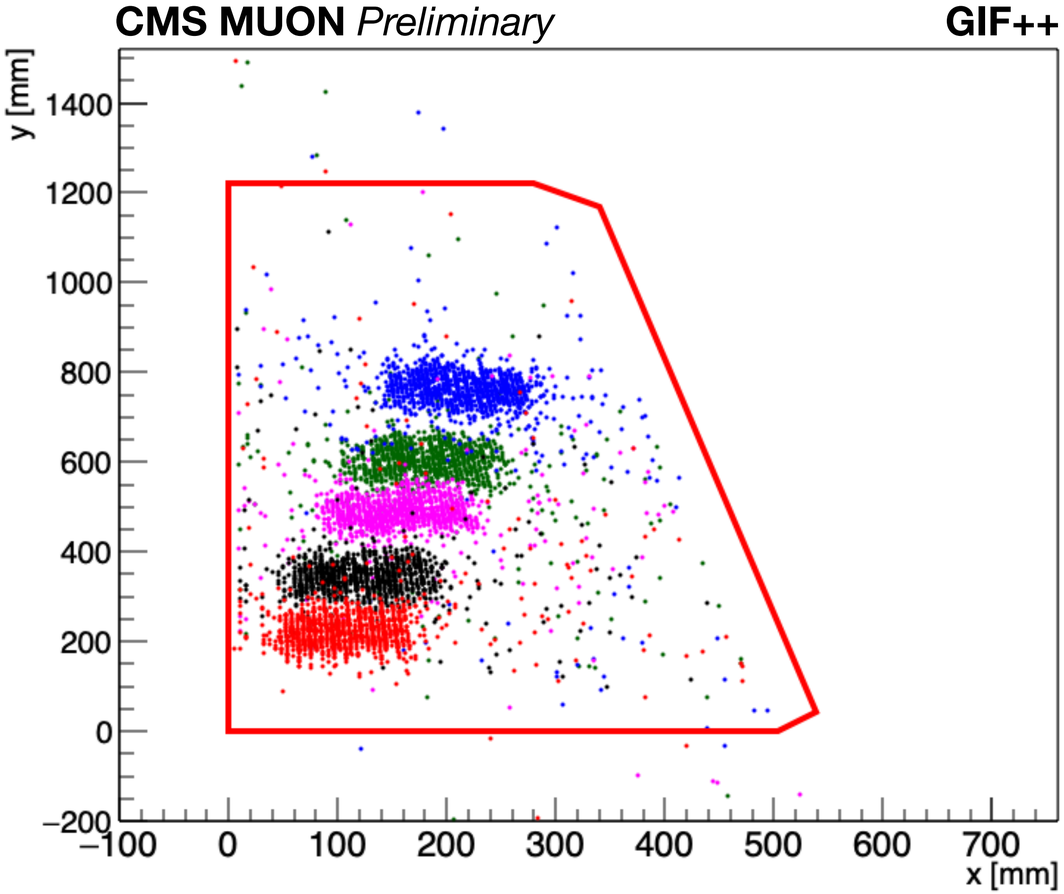
Located at the end of CERN SPS H4 line that provide 150 GeV Muon beam.

Performance of iRPC detector in GIF+

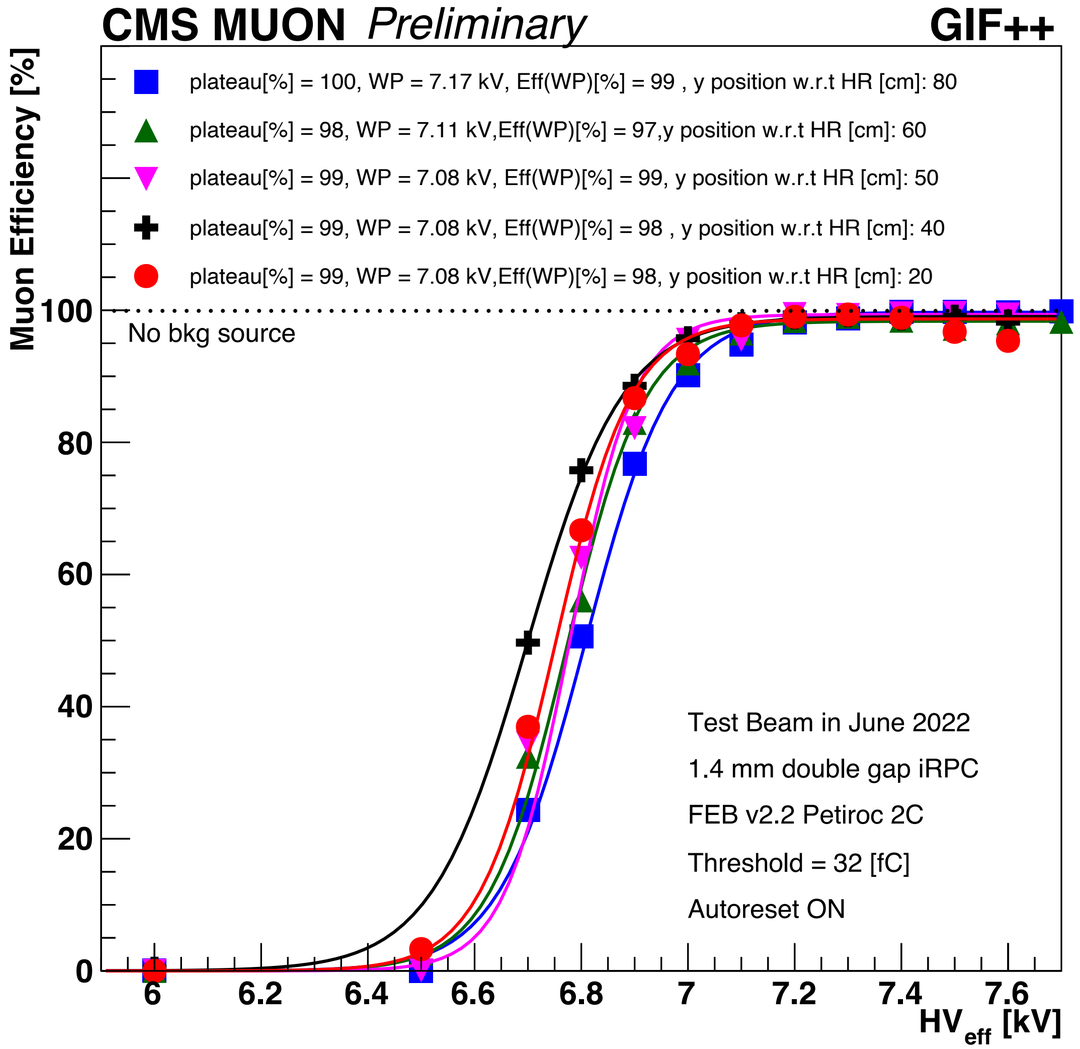
Cluster hits from different regions of the chamber.

The effective high voltage is working point (WP) in the absence of background source.

Successful readout in different locations of the chamber.



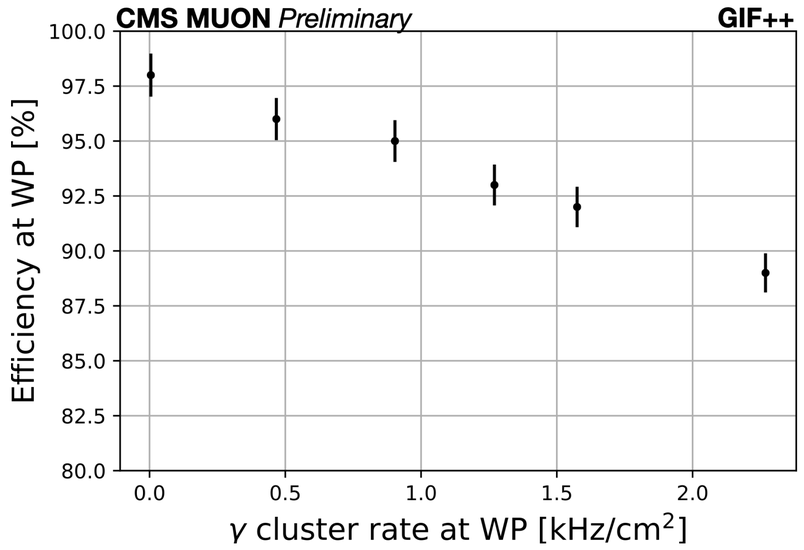
Performance of iRPC detector in GIF++

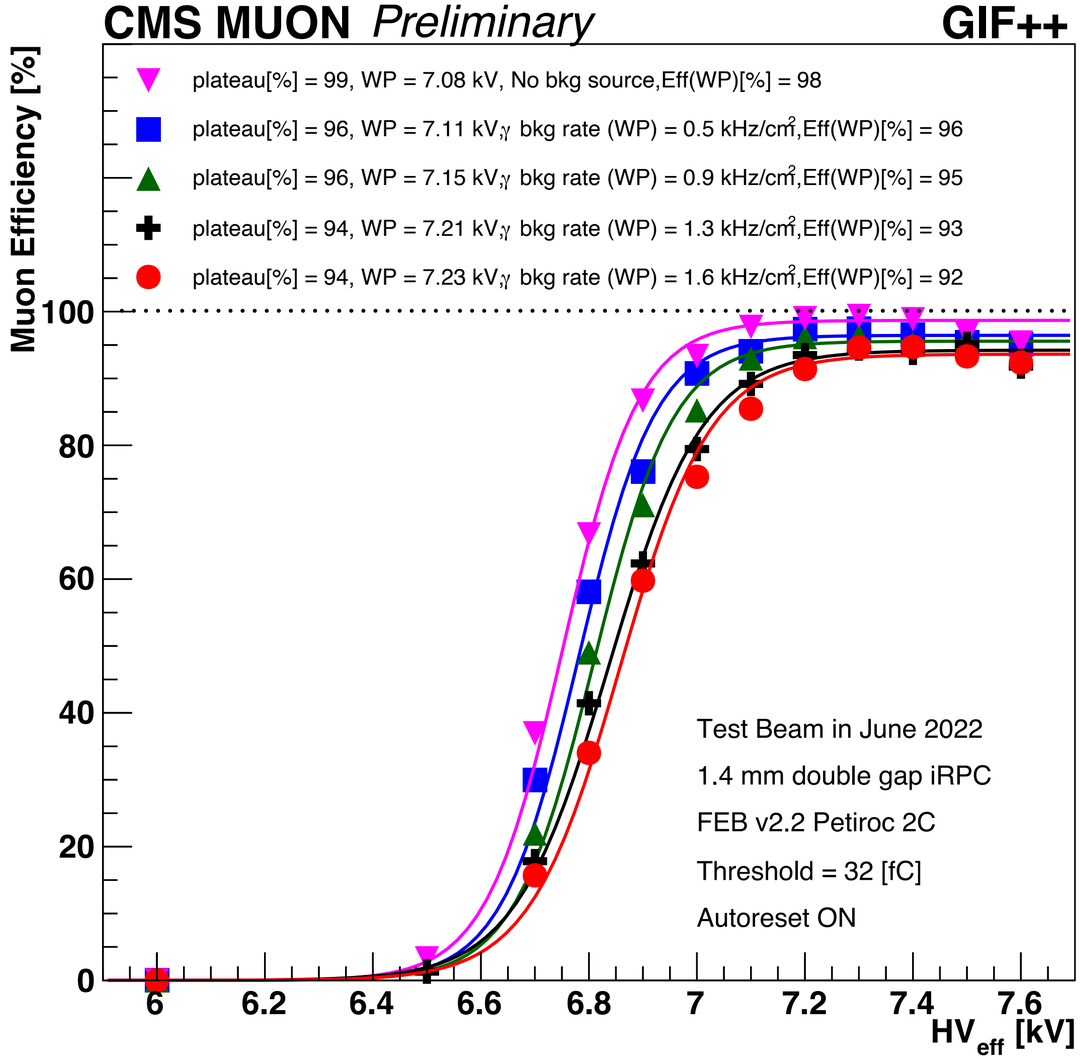


- Efficiency from different regions of the chamber.
- The efficiency at WP is 98±1%.
- The WP is defined as HV_{knee} +120 V.
- The data is collected at the GIF++ facility during the June 2022 test beams.

Performance of iRPC detector in GIF++

Efficiency versus effective high voltage with various background rates at WP.
At 0.9 kHz/cm^2 which is above the expected background rate of Phase II (0.7 kHz/cm^2), the efficiency at WP is measured as 95%.
Estimated efficiency at 2 kHz/cm^2 is ~90%.





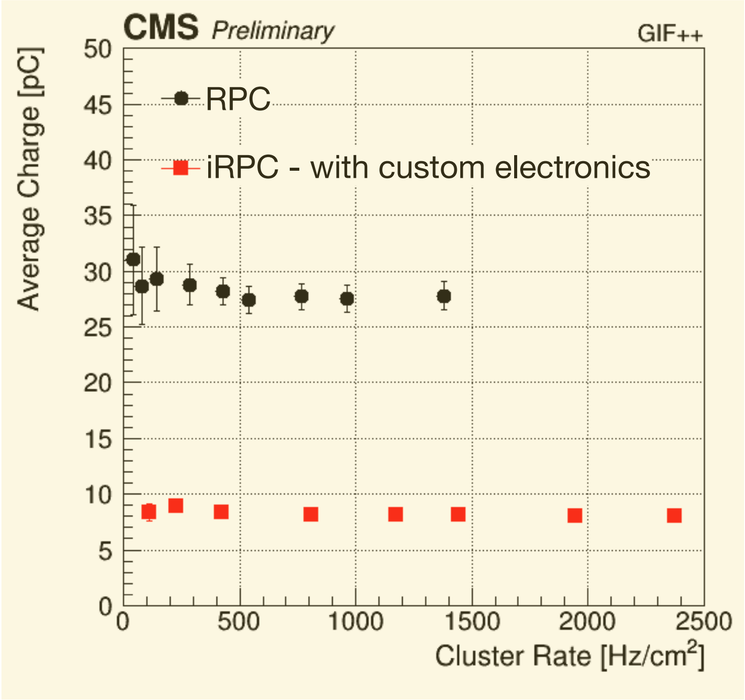
Performance of iRPC detector in GIF++

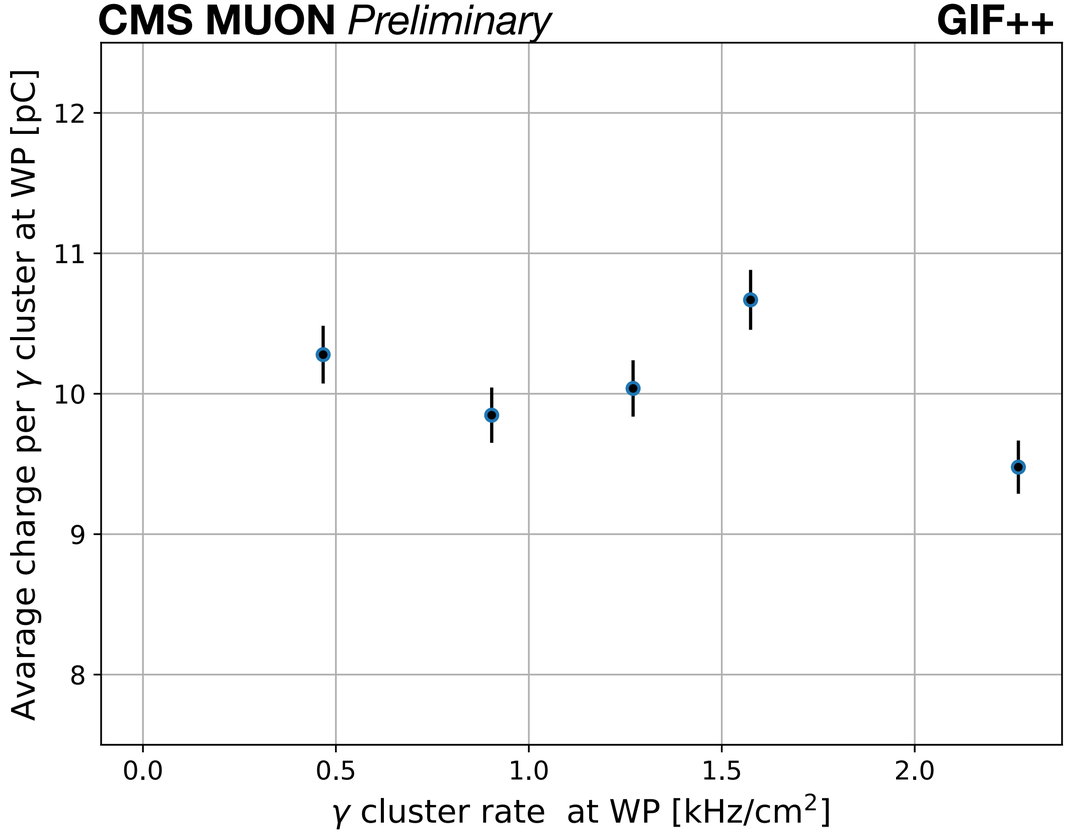
Average charge per gamma cluster

Average charge per gamma cluster at the WP versus gamma background rates at the associated WP

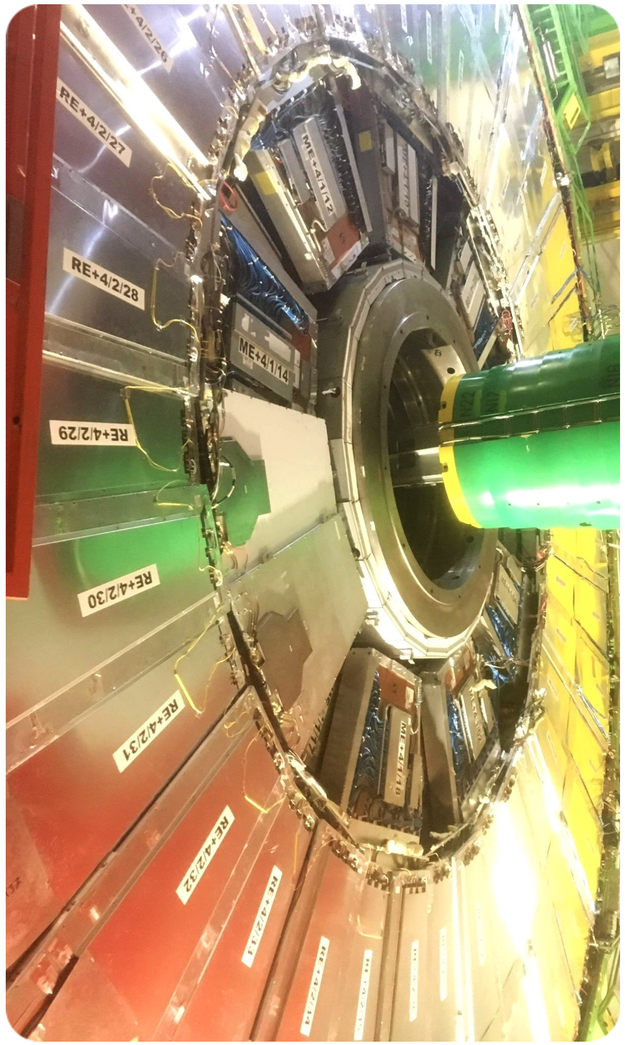
The charge is calculated using the average of the currents measured for two gaps.

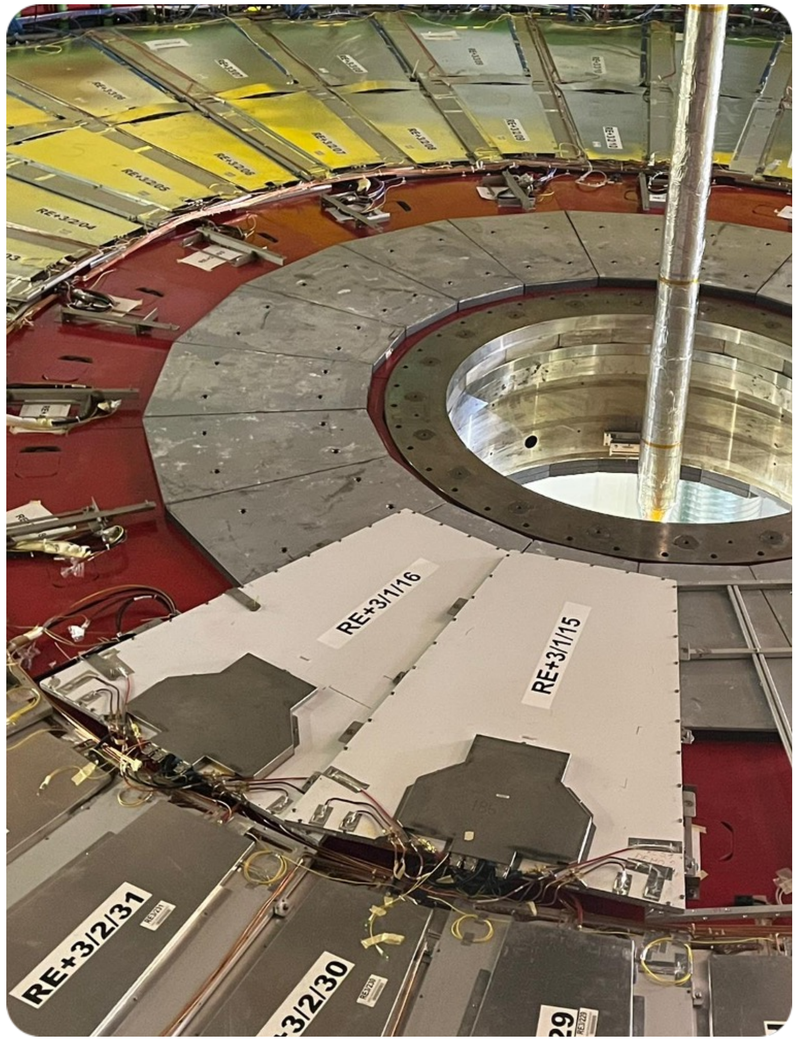
$$< q > = \frac{(I_{TOP} + I_{BOT})/2}{\text{rate}_{\gamma\, CLS} \cdot A_{GAP}}$$





Demonstrator iRPCs are installed



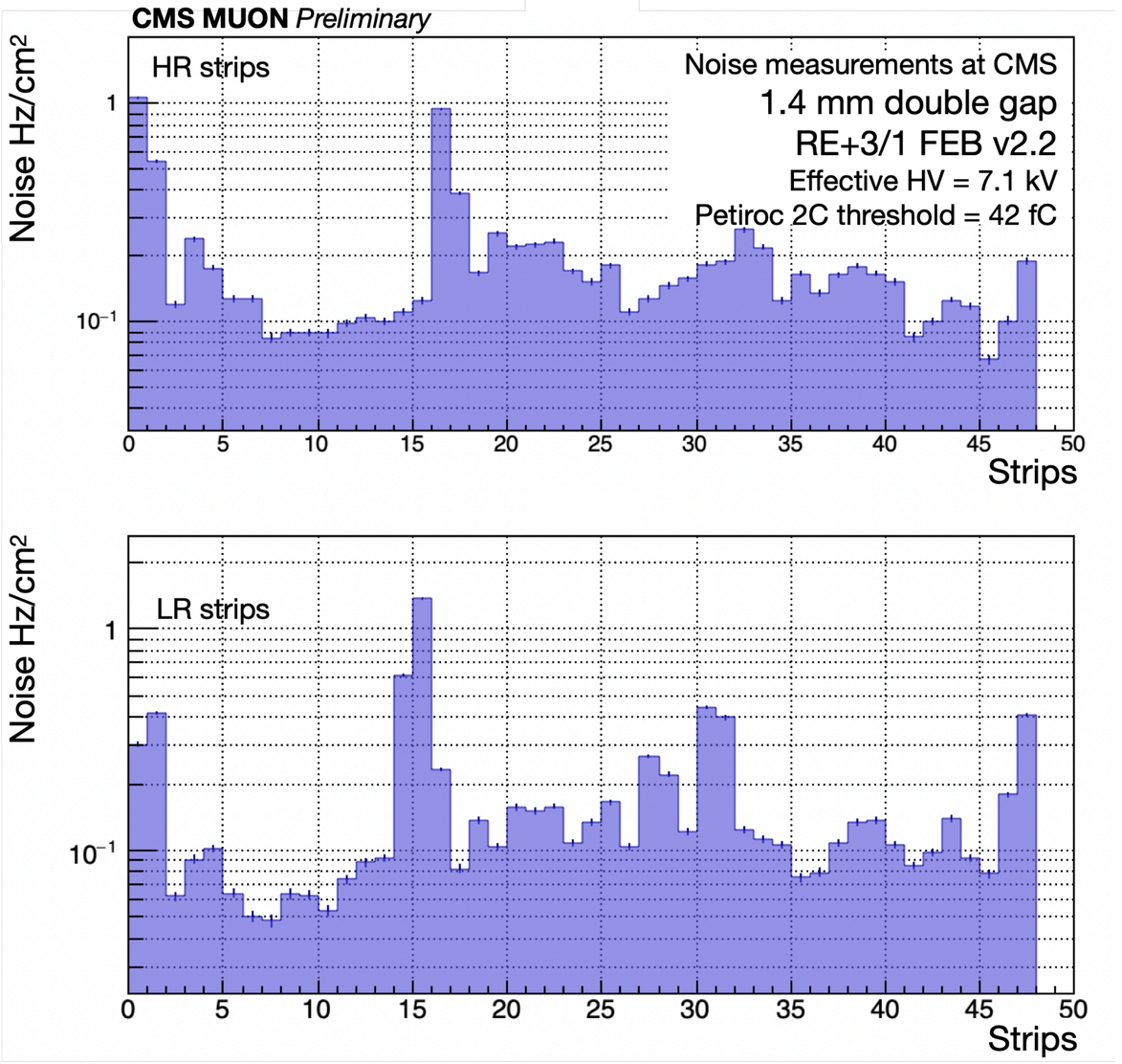


Four demonstrator chambers have just been installed in CMS cavern at the end of LS2. The picture on the left to right exhibit the final position of the demonstration chambers RE+4/1/15,16 and RE+3/1/15,16 respectively.

Performance of demonstrator iRPC

Recent commissioning of demonstrator chambers at CMS Cavern showed/confirmed:

- low noise (~1 Hz/cm^2) with final CMS endcap disk grounding,
- normal/stable operation temperature in CMS endcap closed mode and CMS endcap water cooling,
- no interference with CSC (both RE3/1 and RE4/1),
- normal operation in 3.8T magnetic field



Conclusion

- The Front end electronic is validated.
- iRPC Validation with and without background are successful.
- Irradiation studies with gamma and neutron are successful.
- Commissioning of demonstrator chambers at CMS Cavern is successful.

As a result of successful performance at CERN 904 Lab, GIF++ and at the CMS cavern, currently, demonstrator iRPCs are getting ready for taking data during Run3 to further validate the performance for Phase II operations.